INTRODUCTION TO SECONDARY NETWORK DISTRIBUTION SYSTEMS AND ISSUES RELATED TO THE INTERCONNECTION OF DISTRIBUTED RESOURCES

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Introduction to Secondary Network Distribution Systems and Issues Related to the Interconnection of Distributed Resources

A Distribution Grid and Spot Network Systems

A.1 Scope and Purpose

This document addresses the technical considerations associated with the interconnection of Distributed Energy Resources (DER) to Secondary Network Distribution Systems (or simply Network). It provides an overview of the characteristics of various distribution systems and interconnection requirements, and identifies unique issues that are specific to Network interconnections.

The purpose of this document is to identify the Network-specific interconnection issues for which test protocols should be developed, and to assist in the design of the test facility and development of test plans. Finally, recommend criteria and requirements for interconnection of DER with Secondary Network Distribution Systems is presented.

A.2 Introduction

To clarify the unique characteristics of Grid and Spot Network service, it is desirable to briefly review common modes for distributing electric power.

Utilities utilize various types of distribution systems to serve their customers with reliable and quality power. The most commonly used distribution system is a simple radial circuit that can be either 100% overhead or underground, or a combination of both. The following items summarize the most common distribution feeder characteristics and classifications:

1. The distribution voltage classes for most utilities are 5kV, 15kV, 25kV, and 35kV.

2. The length of radial distribution lines can be less than a mile to in excess of 20 miles. This distance is from the substation to the furthest service point, not the total mileage of all branches.

3. A distribution line load can be as high as 1200 amperes but the range of 300-400 amperes is common.

4. The short circuit duty at each distribution substation varies depending on the transformer size and the voltage class, ranging from 10 kA to 50 kA.

5. Distribution feeders include various control devices. The most common control devices are shunt capacitors to meet local VAR requirements or to support voltage regulation.

Voltage boosters or voltage regulators are also used to maintain adequate line voltage. Series reactors can be employed to limit the fault current. Two winding or auto-transformers may be used on the feeder to change the distribution voltage class.

6. Multi-grounded, uni-grounded, ungrounded, resistively or reactively grounded distribution systems are some of the grounding techniques that are used in the industry. The multi-grounded four-wire distribution system and uni-grounded three-wire distribution systems are most common in North America.

7. Various protective devices are installed on distribution feeders to mitigate potential safety hazards to the public, prevent or minimize damage to equipment and improve service reliability by clearing an abnormal condition through removal of a small section of the circuit for a given fault. Protection of a distribution feeder consists of a circuit breaker at the substation with line reclosers, sectionalizers, interrupters and fuses at intermediate locations along the main feeders and laterals.

The protection devices and philosophy described above do not produce perfect results. Utility attempts to improve reliability are generally focused on 2 methods:

a. Preventive and corrective maintenance.
b. Provision of back up capability at either the primary or secondary voltage levels through manual switching, automatic switching or by Network service.

Examples of switching schemes include primary auto loop scheme, primary selective scheme, and secondary selective scheme. The primary auto loop scheme is applied in radial distribution circuits, the primary selective scheme in concentrated load areas, and the secondary selective schemes in industrial plants and institutions. Maximum reliability and operating flexibility are provided with Spot and Grid Network systems used in congested area such as metropolitan and suburban business districts. Examples of each of these methods of providing electrical service are shown in the following Figures 1 through 6.

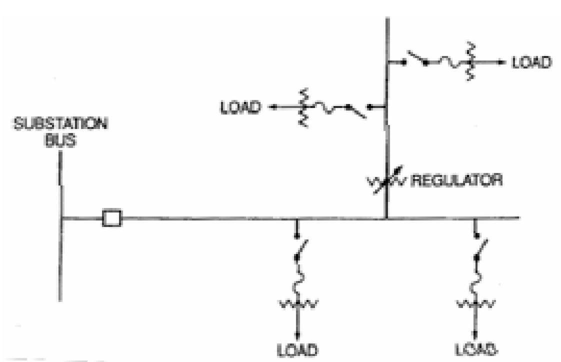

Figure 1 Radial System

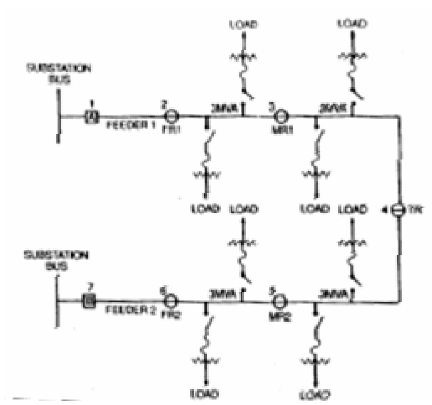

Figure 2 Primary Auto-Loop System

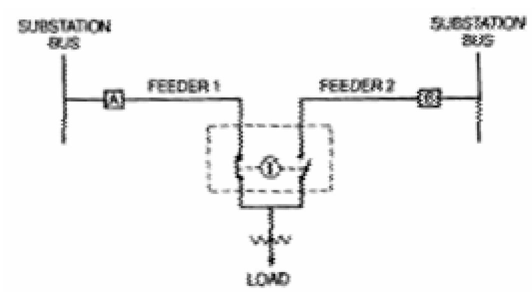

Figure 3 Primary Selective System

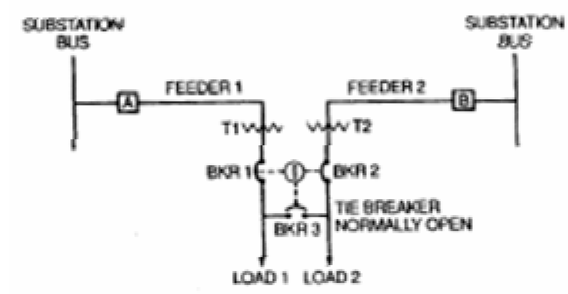

Figure 4 Secondary Selective System

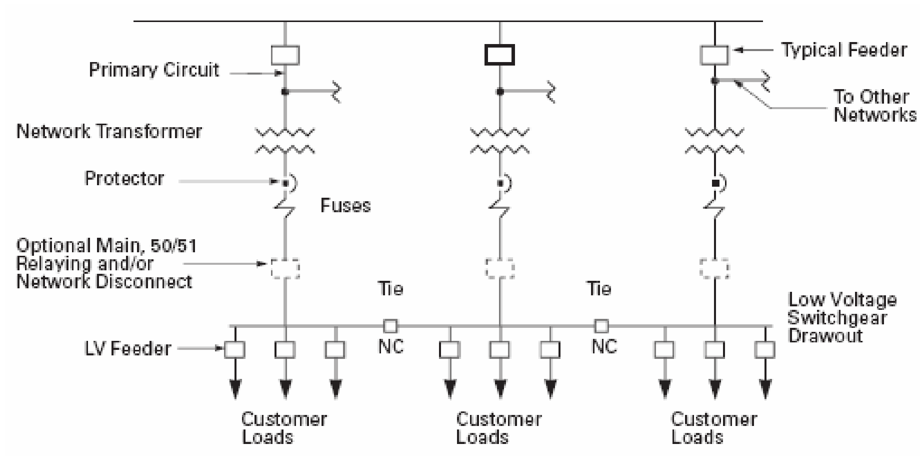

Figure 5 Spot Network System

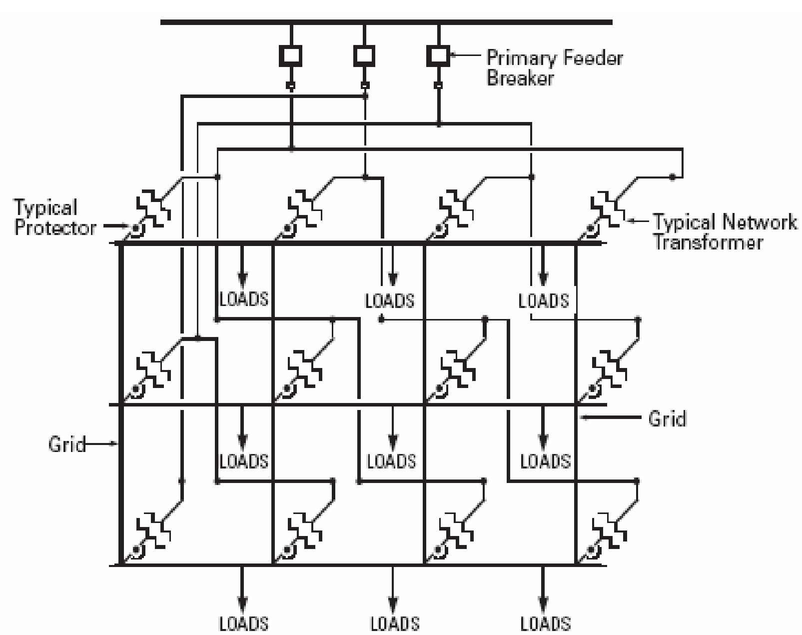

Figure 6 Grid Network System (one primary source shown)

A.3 Definitions

Consistent definitions are critical to understanding the design and operation of Secondary Network Distribution Systems. Alternate definitions for some of the following terms may be found in different regions. These definitions represent, by consensus, the most common usage.

A.3.1 **Cable Limiter:** An enclosed fuse for disconnecting a faulted cable in a Secondary Network Distribution System and for protecting the un-faulted portion of that cable against serious thermal damage**.**

A.3.2 **Cycling:** Undesirable cyclical tripping and closing of a Network Protector due to external (load) conditions. Left unchecked, Cycling may eventually lead to failure of the Network Protector. (Contrast with "Pumping").

A.3.3 **Grid Network:** A Secondary Network System with geographically separated Network Units, with the Network-side terminals of the Network Protectors interconnected by low-voltage cables that span the distance between sites. The low-voltage cable circuits of the Grid Network are typically highly meshed, supplied by numerous Network Units. Also referred to as Area Network or Street Network.

A.3.4 **Network Master Relay:** An electro-mechanical polyphase relay with two functions: 1) opening of the Network Protector when power flow is from the low voltage side to the high voltage side of the Network Transformer; and 2) closing of the Network Protector in conjunction with the electro-mechanical Network-phasing relay when transformer voltage is higher than Network voltage and leads the Network in phase angle.

A.3.5 **Network Protector:** An assembly comprising a circuit breaker and its complete control equipment for automatically disconnecting a transformer from a Secondary Network Distribution System in response to predetermined electrical conditions on the primary feeder or transformer. The device will also connect a transformer to a Secondary Network Distribution System either through manual control or automatic control responsive to predetermined electrical conditions on the feeder and the Secondary Network Distribution System. NOTE—The Network Protector is usually arranged to automatically connect its associated transformer to the Secondary Network Distribution System when conditions are such that the transformer, when connected, will supply power to the Secondary Network Distribution System and to automatically disconnect the transformer from the Network when power flows from the Secondary Network Distribution System to the transformer. [from IEEE C57.12.44-2000]

A.3.6 **Network Protector Fuse:** A backup protective device in series with the Network Protector.

A.3.7 **Network System:** A collection of Spot Networks, Grid Networks, or combinations of such Networks and the primary feeders that supply them.

A.3.8 Network Transformer: A transformer designed for use in a vault to feed a variable capacity system of interconnected secondaries. Note: A Network Transformer may be of the submersible or of the vault type. It usually, but not always, has provision for attaching a Network Protector. (From IEEE C57.12.80-1978). Dry type transformers are also used for Spot Network applications**.**

A.3.9 Network Unit: A Network Unit consists of primary disconnect and grounding switch, Network Transformer, and Network Protector.

A.3.10 Primary Network Feeder: A feeder that supplies energy to a Secondary Network Distribution System or the combination of a Secondary Network Distribution System and other radial loads. (Dedicated Primary Network Feeders supply only Network Transformers for the Grid or Spot Networks; non-dedicated, or combination, feeders supply both Network and radial loads).

A.3.11 Pumping: Rapid, uncontrolled, unintentional and intolerable repetitive tripping and closing of a Network Protector, normally due to a failure in the Network Protector control circuitry. If not promptly detected and corrected, Pumping will quickly lead to failure of the Network Protector. (Contrast with "Cycling").

A.3.12 Secondary Network Distribution System (or "Network"): An AC power distribution system in which customers are served from three-phase four-wire low-voltage circuits supplied by two or more Network Transformers whose low-voltage terminals are connected to the low-voltage circuits through Network Units. The Secondary Network Distribution System has two or more high-voltage primary feeders, with each primary feeder typically supplying between 1 and 30 Network Transformers, depending upon Network size and design. The system includes protective devices designed to isolate faulted primary feeders, Network Transformers, or low-voltage cable sections while maintaining service to the customers served from the low-voltage circuits. Unless otherwise stated, in this document the term "Network" means the Secondary Network Distribution System**.**

A.3.13 Spot Network: A Secondary Network Distribution System consisting of two or more Network Units at a single site where each unit is connected to a separate primary feeder. The low-voltage Network side terminals of these Network Units are connected together with bus and/or cable, with the resultant interconnection structure commonly referred to as the paralleling bus or collector bus. In Spot Networks, the paralleling (collector) bus typically does not have any low-voltage ties to any adjacent or nearby Networks. Such Spot Networks are sometimes called isolated Spot Networks, to differentiate them from Spot Networks with Reach (see below).

A.3.14 Spot Network with Reach: A Spot Network with secondary voltage cable connections to one or more neighboring Spot Networks or to a nearby Grid Network. These reach connections are usually of a capacity limited to the rating of one of the Network Units supplying either Spot Network**.**

A.3.15 Underground Connector: Underground connectors located in manholes and transformer vaults that provide for multiple connections at a single junction point.

A.4 General Secondary Network Characteristics

Though Networks are classified as either Spot or Grid, all Networks share certain characteristics. Those characteristics are described below.

1. Network systems are designed based on the redundant facilities. Any single equipment failure will not result in service outage on the Network.

2. Each Network is served by at least 2 primary feeders.

3. A primary feeder may serve a single Network Unit or many Network Units at different sites, and may also serve radial distribution loads.

4. The primary feeders for a Network system are generally served from a single substation but may be served by different substations. When supplied from different substations, phase angle difference and voltage magnitude difference must be minimized if acceptable operation is to be obtained.

5. The bus configuration at the distribution feeder varies. The configuration can be a single breaker, double breaker with both breakers closed, double breaker with one breaker open and with a transfer switch scheme or sectionalizing bus tie breaker. Utilities also use ring bus arrangements, double synchronizing bus designs, and others such that a bus fault in the station will not result in an outage to more than one primary Network feeder.

6. A Network Unit consists of high side disconnect or grounding switch, Network Transformer, and Network Protector (with master relay, phasing relay and fuses).

7. The primary Network voltage classes range from 5kV to 35kV.

8. Typical Network Transformer sizes are 300, 500, 750, 1000, 1500, 2000 and 2500 kVA. Transformers with 208Y/120 volt secondaries do not exceed 1000 kVA in rating.

9. The transformer impedance is specified in ANSI C57.12.40-2000, and ranges from 4% to 7%.

10. The primary feeder can be either a three-wire or four-wire system.

11. The transformer connections are commonly delta primary – wye grounded secondary for three-wire feeders and wye grounded – wye grounded for four-wire feeders.

12. Protector ratings are given by IEEE Standard C57.12.44 (see appendix). They can be in non-submersible housings, submersible or suitable for mounting within a low voltage switchgear assembly. The ratings of the protectors vary depending on the manufacturer,

the type of the protector and the secondary voltage. Continuous current ratings are from 800 amperes up to 6200 ampere, 216 – 600 Volts. The interrupting ratings are from 30,000 amperes up to 85,000 amperes, and close and latch ratings are from 25,000 amperes to 65,000 amperes.

13. Network Protectors are maximum current rated devices, and have no published overload rating. Protector ratings are generally 33% to 67% higher than the continuous ratings of the transformers they protect to take advantage of short-term transformer overload capability.

A.5 Spot Networks

Spot Network systems are designed to provide 480Y/277 volt or 208Y/120 volt service to a single site (in rare cases, 240 volt delta ungrounded service may be provided). These systems are commonly applied in high load density areas such as metropolitan and suburban business districts. Figure 7 shows two typical Spot Network systems, each with two Network Units.

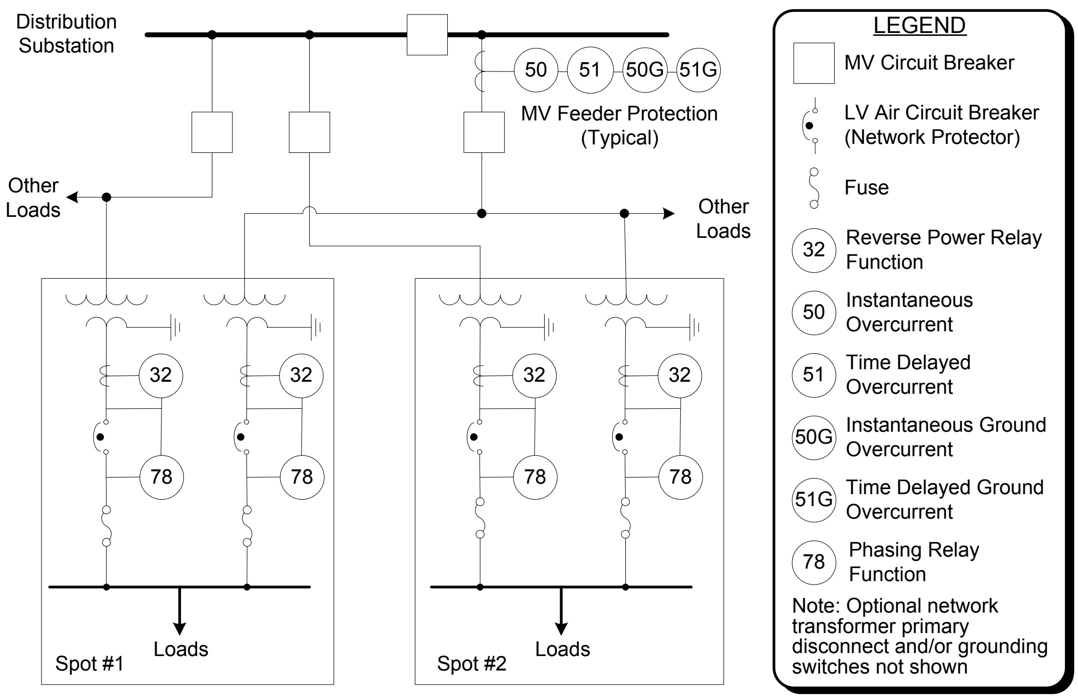

Figure 7 A Pair of Two-Unit Spot Network Systems

Spot Networks have the following characteristics:

1. Most utilities operate each Network system isolated from each other, but some utilities may provide alternative sources to the primary Network feeders.

2. A Spot Network consists of two or more Network Transformers (a three-transformer Spot Network is common) that are paralleled at the secondary bus.

3. In some cases, fast acting secondary bus tie breakers (not present in Figure 7, but as shown in Figure 5) may be applied between bus sections to isolate faults in the secondary switchgear and limit loss of service to only those loads connected to the faulted equipment.

In the Spot Networks of most utilities, a fault or failure of the paralleling bus (collector bus) will result in a service outage. This is one part of the system where redundancy does not exist for most utilities, so its design and integrity is of great importance.

Also, for some utilities, a fault on the medium voltage bus in the substation that supplies the primary feeders will also result in an outage to the Network. Obviously, this does not apply to those utilities that have ring bus designs, double synchronization bus designs, etc for their medium-voltage substations.

A.6 Grid Network

The "Grid" Secondary Network Distribution System consists of an interconnected grid of circuits operating at utilization voltage and energized from a number of primary feeder circuits and Network Units. The number of cables that tie the secondary buses to each other can be anywhere from one to dozens of conductors. These cables are also referred to as secondary mains. The numerous cables allow for multiple current paths from every Network Unit to every load within the Grid

Cable Limiters protect some of these cables ("limit" thermal damage to the cables under fault conditions). Figure 8 shows a portion of a typical Grid Network system fed from a single substation. The grid or mesh is designed so that adjacent network transformers are served by different primary feeders.

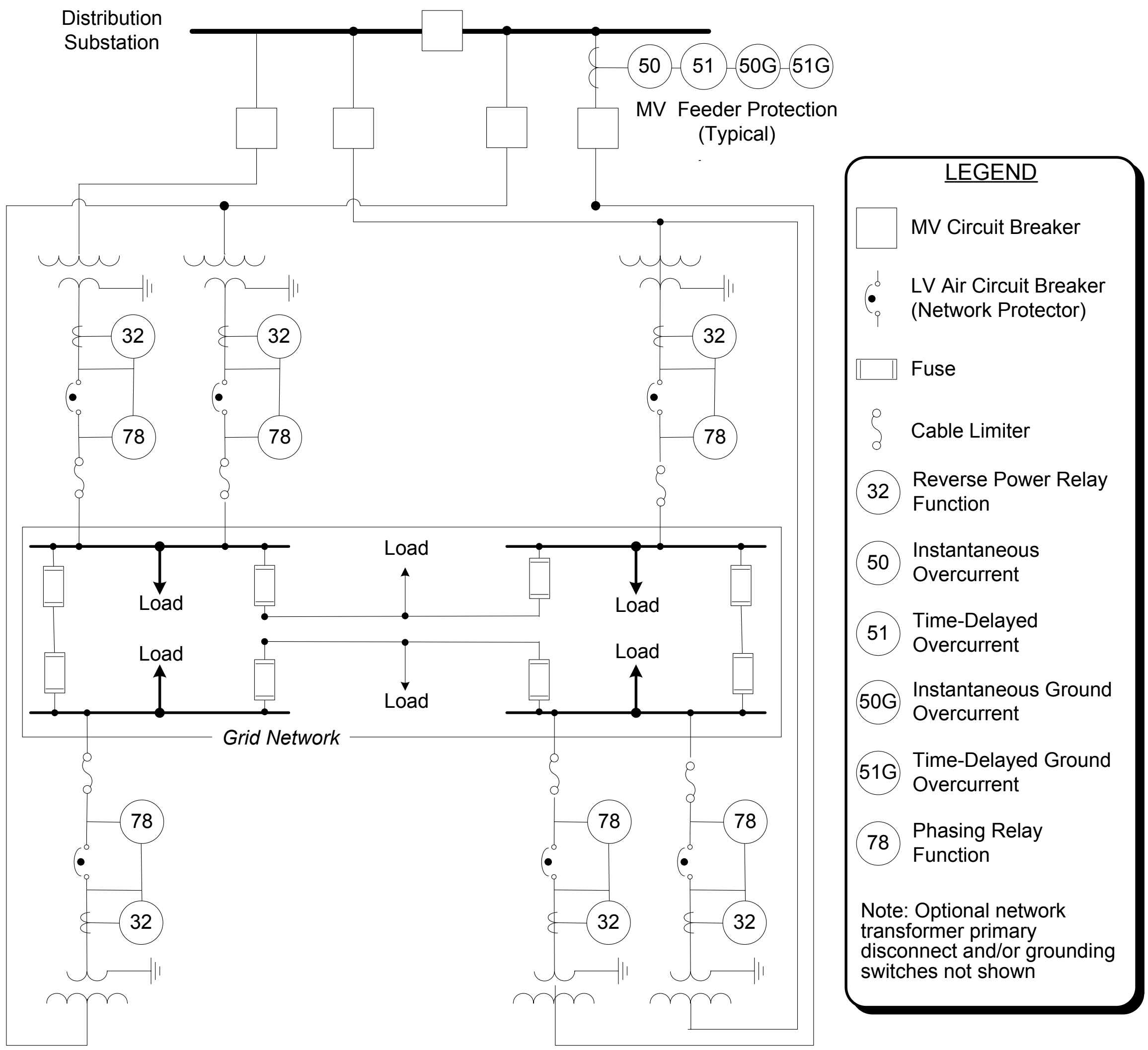

Figure 8 Typical Grid Network System

Grid Networks have the following characteristics:

1. The secondary voltages are either 208Y/120 volt or, in rare cases, 480Y/277 volt.

2. The integrity of the Grid Network is based on multiple paths through individual cables. This integrity is maintained by individual cables, and, if used, Cable Limiters burning clear any faulted cable section.

3. The conductors from which customer service is tapped generally follow the geographical pattern of the load area and are located under streets and alleys.

4. Load flow within the Grid Network will significantly change as a function of

    - MV[1] feeder outage conditions
    - the changing of customer load conditions
    - reduced current carrying capacity due to cleared Cable Limiters

Primary feeder outages and burned-off cables or cleared limiters because of previous faults within the Grid will cause changes in load flow that are not readily detected because the inherent system redundancy generally prevents any customer from experiencing poor power quality. Load flow analysis is necessary to understand the maximum current levels at any point and may be required to determine which Network Units are exposed to Cycling under minimum load conditions.

B Distribution Network Protection Practices

B.1 Protection of Distribution Feeders

De-energizing a faulted feeder in an ordinary radial distribution system requires only a single tripping action: opening the feeder's medium voltage circuit breaker (MVCB) at the supplying distribution substation, assuming there is no DR on the feeder. In contrast, de-energizing a faulted distribution feeder that supplies a Spot or Grid Network system requires at least two (and usually more) tripping operations: 1) open the feeder's MVCB , and 2) open all the Network Protector circuit breakers at the Network Transformers supplied from that feeder.

As shown in Figures 7 and 8, the protective relaying for the MVCB of Network feeders is typically conventional phase and ground overcurrent protection, similar to that used on radial feeders.

The Network Protectors are opened by the Device 32 reverse-power function[2] at each Network Transformer. These operations may be sequential, i.e. some or all of the Network Protectors may not open until the MVCB has opened.

The reverse-power function operates only for real power (watt) flow in the reverse direction, i.e. flow from the low-voltage Network toward the Primary Network Feeder through the Network Transformer. Under non-fault conditions, power flow is normally from the feeder to the Network, so the relay does not trip. When a primary feeder is faulted, the reverse-power function trips from one or more of the following:

(1) real power flow from the Network to the feeder fault

[1] Throughout this document, LV = low voltage (below 600 V) and MV = medium voltage (roughly from 600V to 40 kV)

[2] In Network Units using electromechanical relays, reverse power is one of the two functions incorporated in the Network protection relay that is termed the "master relay." The other function of the master relay is to set the minimum voltage difference that must be present to permit reclosing of the Network Protector. In solid-state and microprocessor-based Network Protector relays, all the required protection functions are incorporated in a single relay.

(2) real power flow from the Network to other loads or Network Units on the feeder
(3) real power flow from the Network to supply the core losses of the Network Transformer

Power flow to the fault (1) is affected by fault type, Network Transformer primary winding connection (delta or wye), and whether the feeder MVCB has opened. Since the master relays are polyphase devices, responding to the net effect of power flow on all three phases, unbalanced feeder faults in the presence of load power flow may not result in a net reverse power flow through the relay and thus may not cause the device to trip.

A case of particular importance is a single-line-to-ground fault on the primary feeder with a Network Transformer primary winding connection of delta. In this case, once the feeder MVCB has opened, the “fault” current is limited to a value permitted by the primary system capacitance, leading to small currents and very little power flow. This case requires great care in design to ensure that a possibly hazardous condition is cleared by the Network Protector control devices.

Reverse power flow to other feeder loads (2) generally only occurs after the feeder MVCB has opened. Its magnitude depends on whether the primary feeder supplies radial loads in addition to Network loads. If the feeder has only Network loads, then it is possible for the magnitude of (2) to be zero.

Because the effects of (1) and (2) may be negligible in some cases, Network protection design usually relies upon (3) to insure that all Network Protectors open for a outage of the primary feeder. Transformer core power losses are very small, typically 0.1 - 1% of the rating of the transformer. Consequently, the reverse power pickup settings of the master relays are very sensitive, on the order of 0.1 – 0.5% of the rated power of the Network Transformer. The very sensitive reverse-power pickup of the Network relays is a major concern in the application of distributed resources on Networks. The slightest amount of power export from the Network, even lasting for just 3 cycles, may open all the Network Protectors serving the facility, thereby creating an island.

B.1.1 Modified Tripping Characteristics

Some Network applications require modification of the basic instantaneous reverse-power protection in order to optimize performance for specific conditions. Microprocessor-based Network relays incorporate these features as optional settings. Modifications to electromechanical Network relays generally require additional devices.

Time-Delayed Trip

Large regenerative loads, such as elevator motors, may substantially reduce the Network real power load for a period of many seconds. In applications where such loads can cause a temporary reversal of power through the Network Unit, it may be desirable to delay the reverse-power trip function in order to avoid unnecessary operations of the Network Protector circuit breaker. Since the time delay is only required for moderate amounts of reverse power (less than or somewhat greater than the rating of the Network Unit), time-delayed trip incorporates a current-supervision function that bypasses the time delay when the Network Unit current is higher than the expected level of reverse-power flow. The net effect is a two level reverse-power function, time-delayed for low levels of reverse power, but instantaneous at higher levels as occur during faults on the primary feeder.[3]

For applications of DR on Network systems, the time-delayed trip modification may be useful for preventing unwanted Network Protector trips that would otherwise be caused by power or fault current flow from the distributed resource.

Watt/VAr Sensing

The basic reverse-power detection function of the Network relays may not always be adequate for the detection of all types of primary feeder faults. Specifically, in a system with single-phase protection devices (fuses) in the primary feeder, or as protection for the Network Transformer, a single-phase to ground fault may result in blowing only one fuse in the MV feeder. In such a case, real power continues to flow toward the Network on the two un-faulted phases while fault current (mostly VArs) flows from the Network toward the primary fault.

Since the reverse-power function reacts to the net power flow of all three phases, it may not be able to detect such a condition. Watt/VAr sensing modifies the characteristic of the reverse-power function, as shown in Figure 9, so that it responds to reverse VArs as well as reverse watts, enabling the Network relay to detect the abnormal supply condition and open the Network Protector.

Because Watt/VAr sensing modifies the relay characteristic to allow tripping on reverse VAr flow, it creates the possibility of unwanted tripping for leading power factor load, and prevents tripping during a capacitive backfeed to the primary feeder. To avoid this possibility, Watt/VAr sensing is usually controlled by the same current supervision function used for time-delayed trip. Thus, pure reverse-power detection is employed at low levels of current with Watt/VAr sensing being switched in at higher levels.[4]

[3] In units with electromechanical Network relays, this time-delay with current supervision function was performed by an auxiliary relay called the "BN" relay. As a result, the feature is often still referred to as the "BN" function in microprocessor-based Network relays.

[4] In one microprocessor-based Network relay, the shift from Watt trip to Watt/VAr trip characteristic was based on the magnitude of the negative-sequence voltage.

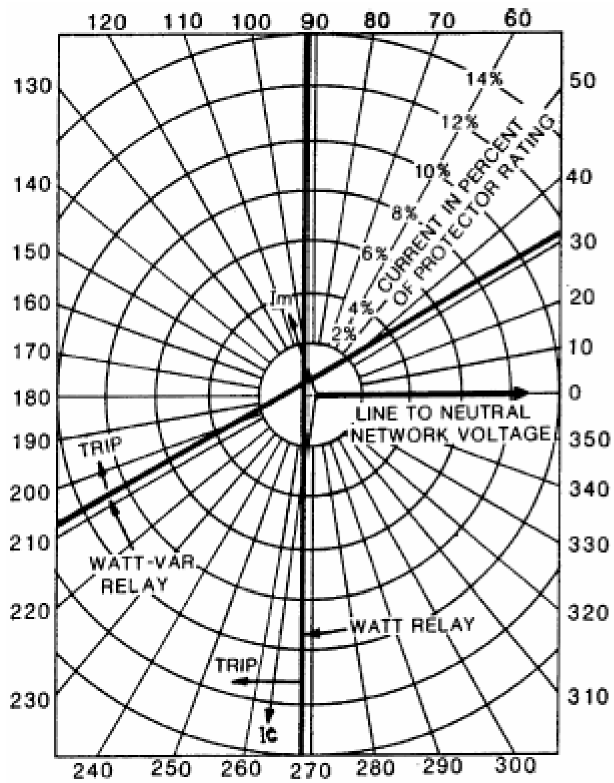

Figure 9 Master Relay Watt and Watt-VAr Trip Characteristics

B.1.2 Restoration

Once the faulted primary feeder has been repaired and re-energized, the Network Transformer units are expected to automatically reclose their Network Protector CB's, restoring their supply to the Network, providing the ensuing Watt and VAr flows will be into the Network.. This reclosing is controlled by the master relay function and phasing relay function.[5] Reclosing supervision by these relays ensures that the Network Protector will not immediately re-open from reverse power flow.

Installation of DR on a Network system may interfere with this automatic reclosing feature by offsetting the Network load to a point where an open Network Protector cannot reclose because the Network voltage or phase angle is outside permissive closing boundary. Modifying the relay reclosing settings to accommodate the DR may lead to more frequent Network Protector opening under light load conditions.

Network phasing relays are designed to measure phase angle under the static conditions that normally occur in Network systems, i.e. the phase angle is either slightly leading or lagging. They are not equipped to deal with rotating phase-angle conditions such as might occur if the

[5] In Network systems using electromechanical relays, separate "master" and "phasing" relays operate together to supervise reclosing. The master relay sets the minimum voltage by which the Network Transformer secondary voltage must exceed the Network voltage to permit reclosing. The phasing relay sets the angle by which the transformer secondary voltage must lead the Network voltage, in order to assure that real power will flow from the transformer to the Network when the Network Protector is closed. Microprocessor-based based Network relays combine these functions, plus the reverse-power protection, in a single relay.

Network were being supplied from an isolated distributed resource while the Network Units were attempting to reclose. If such a condition were to occur, the Network Protector breakers would be likely to "pump," i.e., repeatedly open and close, paralleling and separating the two systems, until the Network Protector fails. It is also possible that the Network Protector would close out of phase, damaging the DR, the Network Protector, or both. Network relays were never intended to control closing of the Network Protector when the systems on either side of the protector are not synchronized.

B.2 Protection of Network Transformers

Protection practice for Network Transformers differs from that of conventional distribution transformers in two important ways:

- MV transformer fuses are often not used because, since service to the Network loads is not interrupted, it is deemed acceptable to de-energize the entire primary feeder for a Network Transformer fault
- It's necessary to open the low-voltage connection to the transformer as well as the high-voltage side since the Network is a source of supply to the faulted transformer

Faults in the MV cable connections to the transformer, disconnect and grounding switch, tap changer, or on the MV winding, are similar in magnitude to the feeder faults discussed above and are cleared similarly. Faults in the transformer's low-voltage winding are isolated from the Network by opening the Network Protector breaker, but have longer clearing times from the high-voltage side because the impedance of the transformer limits the fault current seen by the feeder overcurrent relays. Further, ground faults in the low-voltage winding, or the LV leads, are not detected by the feeder ground relays if the transformer high-voltage winding is delta-connected. In some cases, the feeder relays may not clear a low-voltage fault until sufficient transformer damage occurs so as to involve the high-voltage winding.[6]

Fuses in the low-voltage leads of the Network Protector provide backup protection for the Network Protector for faults on the primary feeder or in the Network Transformer, and also serve to isolate the Network Unit from the Network for LV faults between the Network relay CTs and the fuses. To ensure selective fault clearing of such faults, it is necessary that Cable Limiters and the secondary fuses of adjacent Network Transformers coordinate with the secondary fuse of the faulted Network Unit. Such coordination is aided by the multiplicity of fault current sources and the single fuse in the path of the total fault current. However, such coordination is not possible in the case of a two-unit Spot Network.

B.3 Network Protectors

The Network Protector basically consists of a special air power breaker, a breaker operating mechanism, Network relay and control equipment. Units are available in both semi-dustproof and submersible enclosures for either separate or transformer throat mounting. Switchgear mounting is also possible.

[6] ANSI/IEEE Std. C37.108, IEEE Guide for the Protection of Network Transformers, discusses this problem in detail and provides suggestions for improving the capability to detect and clear Network Transformer faults.

Design and operational description for these devices can be obtained from manufactures of the protectors (Cutler-Hammer and Richards Manufacturing Company). It should be noted that the interrupting capability of the Network Protector breakers is designed for the fault current levels (magnitude and X/R ratio) which are ordinarily encountered in low-voltage Network systems. Network Protectors are typically designed for X/R ratios in the range of six to eight, whereas breakers are designed for X/R ratios greater than 20. Concerns have been raised about the capability of the Network Protectors to successfully interrupt fault currents in systems where distributed resources are applied that significantly changes fault current magnitudes or X/R ratios, though Network Protectors are currently operating on Network systems with X/R ratios above eight.

B.4 Grid Network Cable Protection

Underground cables connect secondary buses and other junction apparatus (e.g., “moles”, and “crabs”) in the Grid Network system to each other. The number of the cables per phase and cable size selection depends on the maximum possible load flow on these cables. The number of cables can be anywhere from one cable per phase to dozens.

Cable-to-Cable Limiters protect these cables. Limiters are designed for 4/0, 250, 300, 350, 400, 500 and 750-kcmil cables, are available for connecting cables to buses and to moles, and are included in “fusible crabs”. These Limiters should coordinate with the Network Protector fuses and the insulation damage characteristics of cable.

Some utilities do not use Limiters for cable sizes of 4/0 and smaller, because it is assumed that cables are small enough to burn clear.

B.5 Customer Protection

The protection device at the customer service point is usually a main breaker, but in older facilities fuses might be utilized instead of the main breaker. It is important that this device be properly coordinated with each of the Network Protector fuses and secondary tie breakers (if present).

C Interconnection Requirements

C.1 Introduction

The increasing demand for interconnection of distributed resources with utility distribution systems has led utilities to establish their own uniform interconnection procedures and requirements. Although each utility has created its interconnection requirements based on its own power system, to a large degree general requirements are common throughout the industry.

In California, interconnection requirements between the three investor owned utilities have been harmonized through the California PUC Electric Rule 21. ER21 itself has been harmonized with

IEEE 1547-2003 interconnection standard. These standards specify that distributed resources must be equipped with protection devices that can detect electrical faults in the system and immediately remove the appropriate unit(s) from the utility Network to eliminate their contribution of fault current into utility's system. Other general requirements address the need for manual load break disconnect devices, dedicated transformers and islanding detection. The protection requirements for the DR facilities are based on their output capability, the type of generator (synchronous, induction, DC inverter) and the point of interconnection.

C.2 General Requirements

IEEE 1547 provides a uniform standard for interconnection of distributed resources with electric power systems. The standard provides technical specifications and requirements in the following areas:

- 4.1 General requirements
- 4.2 Response to Area EPS abnormal conditions.
- 4.3 Power quality
- 4.4 Islanding

Network interconnection is addressed under general requirements, which provides guidance for Spot Networks and leaves Grid Networks "under consideration for future revisions of this standard." .Some have complained that the specifications for Spot Networks are worded in such a way that nearly all Spot Network interconnections will be subject to a site specific engineering review to determine actual requirements (1547 acknowledges that systems larger than 5% of the Spot Network's maximum load may require study to determine if the requirements can be met.). Various state and local jurisdictions are attempting to develop interconnection requirements for Network systems using 1547 guidance.

Network service is a premium service. The higher reliability delivered comes at a higher cost than the more common radial distribution system. Operation, maintenance, and design tend to be assigned to specialists within a given utility. These conditions, along with generally higher fault levels available, the age and evolved response characteristics of most Network hardware, and the lack of experience by utility people in connecting major DG sources have, so far, limited the development of comprehensive interconnection requirements for Network systems. A thorough discussion of problems and solutions is necessary to avoid degrading the advantages of Network service. In the following section, such issues are listed with the goal of identifying engineering solutions or defining tests to support solutions.

C.3 Network-Specific Interconnection Issues

There are unique problems associated with the interconnection of DR to Network distribution systems. The issues vary depending on whether the interconnection is made radially on a primary feeder that supplies a Network, on a Spot Network, or on a Grid Network. The tables on the following pages describe the various issues that need to be addressed.

	Issue	Spot	Grid	Primary Fed	Technology Dependent	Questions to Address	Testing Needs
1	All Network Transformers connected to a primary feeder are protected by the feeder's protective relays.			X		How does the DR provide this protection function for all transformers?	
2	Coordination	X	X			What kind of communication is necessary between the protectors and the DR?	
3	DR Impact on Network equipment/operation	X	X			How will the DR cause false tripping or prevent closing of the protectors?	
4	DR Impact on Network equipment/operation	X	X		X	Will any Network equipment be overstressed due to the DR interconnection?	
5	DR Impact on Network equipment/operation	X	X		X	What effects will the DR have on the Network Protector relays, and what are the new relay setting criteria?	
6	DR Impact on Network equipment/operation	X	X			How will the presence of the DR affect the protectors' response to faults outside of their protection zones?	
7	DR Impact on Network equipment/operation	X	X			Is the operation of a single-phase overcurrent device (protector fuse) a concern with the presence of DR?	
8	DR Paralleling requirements	X	X		X	What conditions must be satisfied before paralleling is allowed? What will be the paralleling procedure?	

	Issue	Spot	Grid	Primary Fed	Technology Dependent	Questions to Address	Testing Needs
9	DR Requirements	X	X			Will a dedicated transformer for the DR be required?	
10	Network configuration	X	X			How do requirements vary with the number of Network Transformers?	
11	Network Configuration	X	X			Will requirements be different for 208 volt and 480 volt Networks because of the different arcing characteristics?	
12	Network Configuration		X			Will the presence of, or lack of, Cable Limiters on the secondary cables result in different DR interconnection requirements?	
13	Network Configuration		X		X	Will the presence of dozens to hundreds of Network Transformers spread out over a wide area result in different requirements?	
14	Network Configuration		X		X	Will changes in power flow over the daily or weekly load cycle result in protector Cycling at a point remote from the DR's PCC?	
15	Network line configuration	X	X			Will different protection requirements apply to Network systems supplied from three-wire and four-wire primaries? With delta-wye or wye-wye transformers?	

	Issue	Spot	Grid	Primary Fed	Technology Dependent	Questions to Address	Testing Needs
16	Protector breakers are not designed to interrupt fault current from generators or withstand out-of-phase conditions across the open switch.	X	X	X	X	How will the protector be prevented from isolating distributed resources from the utility system?	
17	Reverse power through Network Protector	X	X			What would be an acceptable ratio of the minimum customer load current over the maximum DR output to eliminate any possibility of reverse power through a protector?	
18	Reverse power through Network Protector What action needs to be taken with a sudden loss of large load?(Note this really a subset of 4)	X	X			What action needs to be taken with a sudden loss of large load?	
19	Reverse Power through Network Protector	X	X		X	Can power swings or loss-of-synchronism by rotating generators cause reverse power through a Network Protector?	
20	Unintentional Islanding within the Network	X	X		X	If the DR islands, how will the master relay may be prevented from reclosing the protector switch during an out-of-synchronism condition?	

The tables below were prepared for a Network experts meeting held in January 2005 as a way of organizing the discussion of Issues related to the interconnection of DR in Networks. The tables present issues categorized under the topic and subtopic heading: Network Design/Settings, (Size, type, # of Network Units), Voltage, NP Settings, NP False Trip- Reverse Power Fault, DR Design & Operation-Normal Conditions-Fault Conditions -Coordination settings, communications, and Islanding. Each category/subcategory has its own table in which to enter specific issues, what major conditions apply to that issue, what solutions and needs are believed to exist and a column for prioritization.

General Topic: Network Design/Settings
Subtopic: Size, type, # of Network Units, Voltage

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: Network Design/Settings
Subtopic: NP Settings

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: NP False Trip
Subtopic: Reverse Power

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: NP False Trip
Subtopic: Fault

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: DR Design & Operation
Subtopic: Coordination (settings, communications, ...)

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: DR Design & Operation
Subtopic: Normal Conditions

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: DR Design & Operation
Subtopic: Fault Conditions

Priority	**Specific Issue**	**Spot**	**Grid**	**Primary Fed**	**Technology Dependent**		**Solutions/Needs**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic: Islanding
Subtopic:

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

General Topic:
Subtopic:

Priority	Specific Issue	Spot	Grid	Primary Fed	Technology Dependent		Solutions/Needs
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**
							Known: **Hardware:** **Analytical:** **Testing:**

D. References

1. ANSI C57.12.40-2000, ANSI Requirements for Secondary Network Transformers -- Subway and Vault Types (Liquid Immersed).

2. IEEE Standard C57.12.44-2000, IEEE Standard Requirements for Network Protectors.

3. IEEE Standard C37.108-1994, IEEE Guide for the Protection of Network Transformers.

4. IEEE Standard 1547-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.

5. California Public Utilities Commission, Electrical Rule 21, Generating Facility Interconnections.

6. "Spot Network Equipment", Eaton/Cutler-Hammer Document #0453, January 2003.

7. R. C. Settembrini, J. R. Fisher, and N. E. Hudak, "Reliability and Quality Comparisons of Electric Power Distribution Systems", IEEE Power Engineering Society, Transmission and Distribution Conference, 1991.

Appendix. Network Protector Ratings

IEEE Standard C57.12.44-2000 establishes minimum requirements for Network Protector continuous current, interrupting current and closing and latching current, as shown in Tables 1 and 2. The close and latch ratings apply only to Network Protectors that have spring close or stored energy mechanisms. Network Protector ratings exceed transformer nameplate current ratings so that short term overload capability of the transformer may be exploited.

Table 1 IEEE Network Protector Ratings at 216/125V

Network Protector			Network Transformer		
Continuous Current Rating (A_{rms})	Interrupting Current (A_{rms} symmetrical)	Close and Latch Current (A_{rms} symmetrical)	Nameplate Rating (kVA)	Nameplate Current (A_{rms})	Protector rating (% transformer nameplate)
800	30,000	25,000	225	600	133
1200	30,000	25,000	300	800	150
1600	30,000	25,000	500	1333	120
1875	30,000	25,000	500	1333	141
2000	35,000	35,000	500	1333	150
2250	35,000	35,000	500	1333	169
2500	60,000	40,000	750	2000	125
2825	60,000	40,000	750	2000	141
3000	60,000	40,000	1000	2667	112
3500	60,000	40,000	1000	2667	131
4500	60,000	40,000	1000	2667	169

Table 2 IEEE Network Protector Ratings at 480/277V

Network Protector			Network Transformer		
Continuous Current Rating (A_{rms})	Interrupting Current (A_{rms} symmetrical)	Close and Latch Current (A_{rms} symmetrical)	Nameplate Rating (kVA)	Nameplate Current (A_{rms})	Protector rating (% transformer nameplate)
800	30,000	25,000	225	600	133
1200	30,000	25,000	750	900	133
1600	30,000	25,000	1000	1200	133
1875	30,000	25,000	1000	1200	156
2000	35,000	35,000	1000	1200	167
2250	35,000	35,000	1000	1200	188
2500	45,000	40,000	1500	1800	139
2825	45,000	40,000	1500	1800	157
3000	45,000	40,000	2000	2400	125
3500	45,000	40,000	2000	2400	146
4500	60,000	40,000	2500	3000	150
5000	60,000	40,000	2500	3000	167